

PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION  
International Bureau



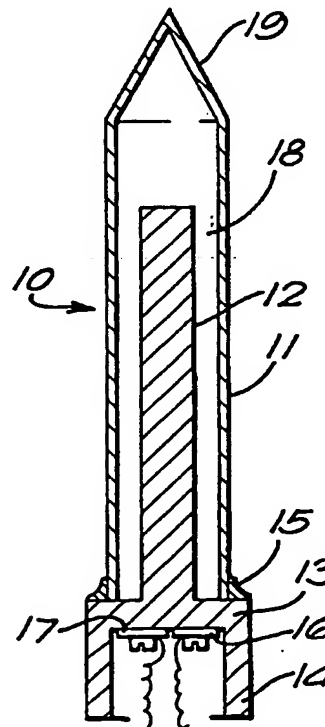
INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

<p>(51) International Patent Classification <sup>5</sup> : G01N 9/00, G01F 23/28, 1/84, G01N 11/16</p>	<p>A1</p>	<p>(11) International Publication Number: WO 94/14047 (43) International Publication Date: 23 June 1994 (23.06.94)</p>
<p>(21) International Application Number: PCT/GB93/02453 (22) International Filing Date: 29 November 1993 (29.11.93) (30) Priority Data: 9225983.7 12 December 1992 (12.12.92) GB (71) Applicant (for all designated States except US): HYDRAMOTION LIMITED [GB/GB]; New York House, 1 York Road Industrial Park, Malton, North Yorkshire YO17 0NW (GB). (72) Inventor; and (75) Inventor/Applicant (for US only): GALLAGHER, John, Gerard [GB/GB]; 77 Town Street, Malton, North Yorkshire YO17 0HD (GB). (74) Agent: HORTON, Andrew, Robert, Grant; Bowles Horton, Felden House, Dower Mews, High Street, Berkhamsted, Hertfordshire HP4 2BL (GB).</p>		<p>(81) Designated States: GB, US, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).  Published With international search report.</p>

(54) Title: TRANSDUCER FOR THE MEASUREMENT OF ATTRIBUTES OF FLOWABLE MEDIA

(57) Abstract

A transducer for the measurement of density, viscosity, flowrate or suchlike of fluids or flowable solids comprises a resonator having two vibratile beam elements (11, 12), one of which is disposed coaxially within the other. The outer element (11) may be a closed tube which forms a chamber around the inner element (12). Drive means (16) and sensing means (17) may be disposed on a base (13) which provides a common root for the beam elements.



BEST AVAILABLE COPY

*FOR THE PURPOSES OF INFORMATION ONLY*

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria	GB	United Kingdom	MR	Mauritania
AU	Australia	GE	Georgia	MW	Malawi
BB	Barbados	GN	Guinea	NE	Niger
BE	Belgium	GR	Greece	NL	Netherlands
BF	Burkina Faso	HU	Hungary	NO	Norway
BG	Bulgaria	IE	Ireland	NZ	New Zealand
BJ	Benin	IT	Italy	PL	Poland
BR	Brazil	JP	Japan	PT	Portugal
BY	Belarus	KE	Kenya	RO	Romania
CA	Canada	KG	Kyrgyzstan	RU	Russian Federation
CF	Central African Republic	KP	Democratic People's Republic of Korea	SD	Sudan
CG	Congo	KR	Republic of Korea	SE	Sweden
CH	Switzerland	KZ	Kazakhstan	SI	Slovenia
CI	Côte d'Ivoire	LI	Liechtenstein	SK	Slovakia
CM	Cameroon	LK	Sri Lanka	SN	Senegal
CN	China	LU	Luxembourg	TD	Chad
CS	Czechoslovakia	LV	Latvia	TG	Togo
CZ	Czech Republic	MC	Monaco	TJ	Tajikistan
DE	Germany	MD	Republic of Moldova	TT	Trinidad and Tobago
DK	Denmark	MG	Madagascar	UA	Ukraine
ES	Spain	ML	Mali	US	United States of America
FI	Finland	MN	Mongolia	UZ	Uzbekistan
FR	France			VN	Viet Nam
GA	Gabon				

BEST AVAILABLE COPY

- 1 -

TRANSDUCER FOR THE MEASUREMENT OF ATTRIBUTES OF FLOWABLE  
MEDIA

5 The present invention relates to transducers for the measurement of attributes of flowable media, for example the density, viscosity, mass flow or the level of a fluid or a flowable solid.

10 It is known for example from GB-B-2202944 to provide a transducer which essentially comprises a resonator in the general form of a tuning fork for the measurement of attributes of flowable media. The fork is usually constructed from two parallel beam elements of which the longitudinal axes are laterally spaced apart. These beam  
15 elements may be tubes which contain the fluid or tines which are immersed in the medium. When tubes are used there is usually a limitation in the size of the bore, limiting the flowrate, and it is usually necessary to provide some means for directing the medium through the tubes, for example a  
20 pump. If the device is adapted for insertion into the flowable medium, there is no need for ancillary equipment such as pipe fittings and the transducer can usually be made smaller and easier to install. However, devices employing a pair of tines are susceptible to error or inconvenience  
25 arising from the entrapment of debris between the tines, such debris effecting the desired vibration and accordingly the accuracy of measurement.

30 The invention is generally concerned with the provision of improved and versatile transducers and more particularly an improved transducer which reduces some of the disadvantages associated with a device comprising a pair of spaced apart tines.

- 2 -

The present invention is based on a structure which in preferred forms can be described as a coaxial resonator, for example a resonator composed of two vibratile beam elements having a common base or root, a first of the beam elements being disposed at least partially within the other. In the manner of a tuning fork, when one beam element, for example the outer beam element, is displaced at its distal end, it creates at its base or root a torque moment, which is equalized by the sympathetic movement of the other beam element, there being practically no net displacement at the common base or root. The structure provides a highly efficient vibrating system, having a natural frequency dependent on the physical characteristics, such as the mass and stiffness of the beam elements.

Various other features and aspects of the invention are more conveniently described with the aid of the accompanying drawings.

#### Brief Description of the Drawings

Figure 1 illustrates in simplified form one embodiment of a transducer according to the invention.

Figure 2 illustrates a second embodiment of a transducer according to the invention.

#### Detail Description of Preferred Embodiments

Figure 1 illustrates by way of example one embodiment of a transducer according to the invention. This transducer is in the form of a coaxial resonator and comprises two vibratile beam elements, one located inside the other. The outer beam element 11 in this example comprises a tube and the inner element 12 is in the form of a substantially solid tine. Both elements 11 and 12 are either integral with or secured to a base or root 13.

- 3 -

Like a tuning fork, when one beam element, for example the element 11, is displaced or vibrated, it vibrates in the manner of a cantilever beam and accordingly creates at its base or root a torque moment, which is equalized by the sympathetic movement of the other beam element to create practically no resulting displacement at the base or root. The result is an efficient vibrating system with a natural frequency dependent on the mass and stiffness of the elements 11 and 12.

In the present embodiment, the base 13 has a rearwardly extending flange 14 defining a well or partial enclosure wherein an appropriate means for inducing vibration in the resonant structure and for sensing either displacement, strain or other characteristic of the resonant structure may be disposed. This is not the only possible location of such drive means and sensing means but the location specified here is particularly convenient for the structure shown in Figure 1. In this embodiment the drive means is constituted by a piezoelectric plate 16 attached to the underside of the base 13 which provides the common support for the vibrating beam elements and the pickup or sensing means is likewise constituted by a piezoelectric plate 17 similarly disposed on the underside of the base 13.

In the present embodiment, the outer element is closed at its distal end by a nose cone 19. Accordingly, when the transducer is inserted into a fluid, only the external surface of the outer element will be in contact with the fluid. The outer element may therefore be a simple, closed cylinder, having a low propensity for obstructing the flow, resisting insertion or for the entrapment of debris. In such an embodiment, since fluid is not permitted within the chamber 18 inside the outer element, the inner element 12 is free to vibrate without any impedance by the fluid.

- 4 -

When immersed into a fluid or flowable solid, the structure is still capable of acting as a resonator, but the resonant characteristics may be modified by the medium in a variety of ways.

5

First, as the outer element is displaced during the execution of its natural vibrations, it displaces fluid having a mass proportional to the fluid density. This displacement increases the effective mass of the outer  
10 element, resulting in a change of resonant frequency of the transducer. By measurement of this resonant frequency the density of the surrounding fluid may be determined.

Second, as the outer element is displaced during the  
15 execution of natural vibration, its surface shears through the fluid, creating a drag force due to viscosity in the outer element. This results in a loss of energy from the vibrating system, manifested by a decrease in the Q (quality factor) of the resonant peak. By measurement of that  
20 quality factor, the viscosity of the surrounding fluid may be determined.

Third, if the transducer is so oriented that the longitudinal axis of the outer element is parallel to the  
25 flow of the fluid, the transducer causes periodic disturbances normal to the flowing fluid, creating a coriolis force across the length of the tube, in proportion to the mass flowrate. This coriolis force can be measured as a variation in oscillatory phase of the outer element,  
30 the measurement being capable of providing an indication of the coriolis acceleration and accordingly the mass flowrate.

Fourth, if the outer element is only partially covered by the external fluid, it will vibrate at a frequency  
35 proportional to the amount of covering fluid in a fluid density. The fluid density can be established from a second, fully covered, vibrating element, so that the

- 5 -

resonant frequency is a function of fluid cover or level. The outer element might be short, such as only ten centimetres, or long, such as ten metres, to embrace the variation required to measure different levels.

5

In a similar way to that just described, the transducer may be used as a level switch. The frequency of vibration in air or a vacuum can be established. The presence of small quantities of material on the surface of the outer element can result in a change of the natural frequency of vibration. By monitoring the resonant frequency of the apparatus, one may indicate the presence or absence of material. This configuration of the device is applicable to the detection of non-fluid matter such as particulate solids.

15

The resonant structure may be driven into sustained vibration from a periodic energy source in the appropriate phase and frequency relationships with a mechanical displacement of the vibrating elements. The drive means may be electromagnetic, acoustic, or capacitative, or operate by deformation of piezoelectric devices bonded at some appropriate point, as shown in Figure 1, and driven using a periodically varying electrical signal. The vibration may be sensed by a variety of techniques which create an electrical signal in response to a displacement or strain at a mechanically efficient point in the apparatus. As noted in the foregoing, Figure 1 illustrates the use of a piezoelectric element as a vibration sensor at the base of the apparatus, but many other forms of sensor may be employed.

25

30

The structure can be driven into continuous oscillation by the use of a gain limiting amplifier and the suitable matching of phase between drive and pickup transducers. Feedback from the sensing transducer may be used for this purpose.

35

- 6 -

Further embodiments of the invention may employ inner and outer elements driven at higher cantilever modes of vibration and combinations thereof. For example, the outer element may be tuned to vibrate at its second or third mode  
5 whereas the inner element can be maintained at a fundamental mode. The selection of modes may be based on a choice of mass or stiffness characteristics of the two elements so that there is no resultant displacement at the base of the apparatus or otherwise. Vibration of the outer element at a  
10 higher mode can create greater sensitivity of measurement and improve immunity to variation in mounting conditions at the base.

Figure 2 illustrates an embodiment similar to that shown in  
15 Figure 1, using a fixed or removable extension to the outer element. Those parts of Figure 2 which are common to the embodiment of Figure 1 are denoted by the same reference numbers and will not be described again. In the embodiment of Figure 2, the outer tube 11 has a flat end cap 20, which  
20 carries a vane 21 constituting an extension to the vibrating structure.

If the vane 21 were disposed in a plane normal to the vibration, it would increase the surface area disturbing the  
25 fluid and therefore improve the sensitivity of density measurement. If the vane were disposed at right angles to the position shown, so that it were parallel to the plane of vibration, it would increase the shear surface and thereby improve sensitivity in the measurement of viscosity.

30 The vibrating elements may be elliptical, square, or polygonic in cross-section in accordance with different effects of the section on the measurement of different attributes.

35 Further embodiments of the invention may include a port, for example in the base 13, allowing fluid to flow into the



- 7 -

chamber 18 between the inner and outer elements to equalize the pressure on the outer element and reduce any pressure stress thereon.

- 5 Further modifications to the disclosed embodiments are feasible. For example, the transducer may be incorporated into a system having more than two elements. It may be advantageous to mount the base on a semi-rigid bellows or other means which provides at least some mechanical
- 10 decoupling between the transducer and a structure to which it may be attached.

- 8 -

CLAIMS

1. A transducer for the measurement of attributes of flowable media, comprising a resonator comprising two  
5 vibratile beam elements (11,12) having a common base, characterised in that one of the said two beam elements (12) is disposed at least partially within the other of the said two beam elements.
- 10 2. A transducer according to claim 1 wherein at least an outer one (11) of the said two beam element comprises a tube.
- 15 3. A transducer according to claim 2 wherein the outer beam element (11) is closed at a distal end remote from the base so as to define a chamber around the inner element (12) of the said two beam elements.
- 20 4. A transducer for the measurement of attributes of flowable media, comprising a resonant structure including two laterally spaced elements extending from a common support, characterised in that the said two elements (11,12) have longitudinal axes which are substantially coincident.
- 25 5. A transducer according to claim 4 wherein one of the transducers is disposed at least partly within the other.
- 30 6. A transducer according to any foregoing claim, and including drive means (16) for inducing vibration of the beam elements.
7. A transducer according to any foregoing claim, and including means (17) for sensing at least one attribute of the vibration of the elements.

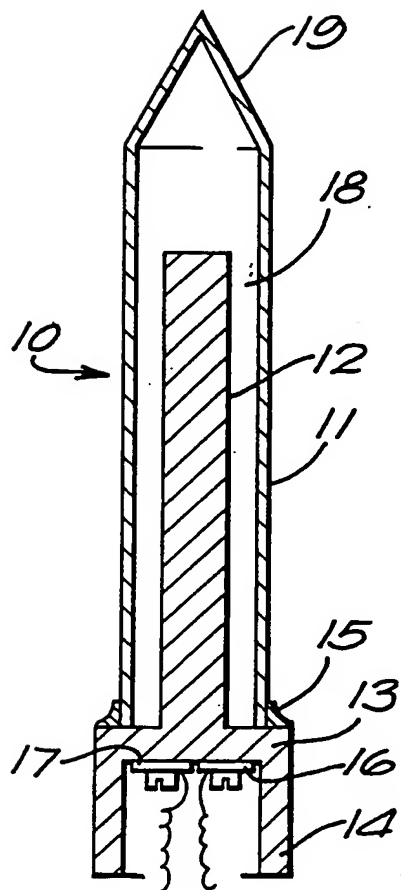


FIG. 1

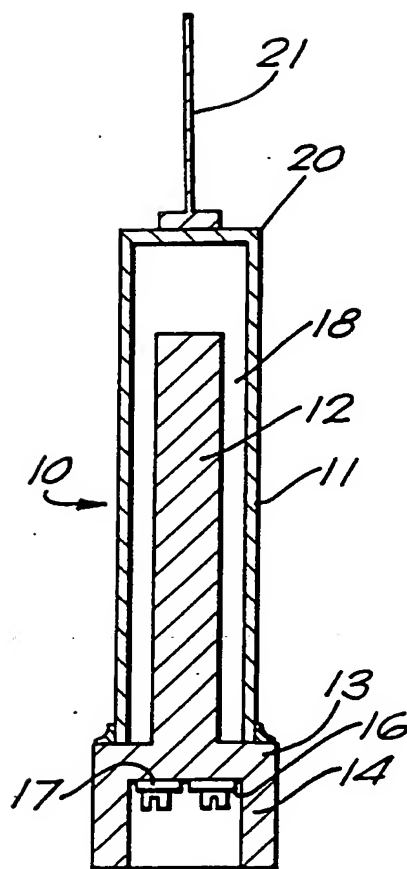


FIG. 2

## INTERNATIONAL SEARCH REPORT

Int: l Application No  
PCT/GB 93/02453

A. CLASSIFICATION OF SUBJECT MATTER  
IPC 5 G01N9/00 G01F23/28 G01F1/84 G01N11/16

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 5 G01N G01F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO,A,83 01307 (VEGA GRIESHABER GMBH) 14 April 1983 see page 2, line 15 - line 28 see page 6, line 3 - line 17; figures 1,2 ---	1-7
A	ELECTRONIC ENGINEERING vol. 53, no. 659, November 1981, LONDON GB pages 159 - 168 LANGDON 'vibratory process control transducers' see page 167, line 1 - line 17 see page 168, column 1, line 15 - line 32 --- -/--	1,4

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

## \* Special categories of cited documents:

- "A" document defining the general state of the art which is not considered to be of particular relevance  
 "E" earlier document but published on or after the international filing date  
 "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)  
 "O" document referring to an oral disclosure, use, exhibition or other means  
 "P" document published prior to the international filing date but later than the priority date claimed

- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention  
 "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone  
 "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art  
 "&" document member of the same patent family

Date of the actual completion of the international search

21 February 1994

Date of mailing of the international search report

4. 03. 94

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2  
NL - 2280 HV Rijswijk  
Tel. (+ 31-70) 340-2040, Tx. 31 651 epo nl,  
Fax: (+ 31-70) 340-3016

Authorized officer

Hocquet, A

# INTERNATIONAL SEARCH REPORT

Int: mal Application No  
PCT/GB 93/02453

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP,A,0 282 251 (SCHLUMBERGER) 14 September 1988 cited in the application see column 3, line 10 - line 42; figure 1 see column 3, line 50 - line 58; figure 2 see column 8, line 26 - column 10, line 17 ---	4-7
X	US,A,4 740 726 (UMEZAWA) 26 April 1988 see column 2, line 41 - column 3, line 16; figures 2,4 ---	1-7
P,X	EP,A,0 564 682 (ENDRESS+HAUSER FLOWTEC AG) 13 October 1993 ---	1-7
A	US,A,3 625 058 (ENDRESS ET AL.) 7 December 1971 -----	1,4

# INTERNATIONAL SEARCH REPORT

information on patent family members

International Application No

PCT/GB 93/02453

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO-A-8301307	14-04-83	EP-A, B 0089336 US-A- 4499765	28-09-83 19-02-85
EP-A-0282251	14-09-88	DE-A- 3878473 GB-A, B 2202944 JP-A- 63308528 US-A- 4922745	25-03-93 05-10-88 15-12-88 08-05-90
US-A-4740726	26-04-88	DE-A- 3734077 GB-A- 2210689	20-04-89 14-06-89
EP-A-0564682	13-10-93	NONE	
US-A-3625058	07-12-71	DE-A- 1773815 CH-A- 491370 FR-A- 2012618 GB-A- 1250537 NL-A- 8103934 NL-A- 8103935 NL-A- 6905224 SE-B- 376652	03-02-72 31-05-70 20-03-70 20-10-71 04-01-82 04-01-82 13-01-70 02-06-75